ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Multi Objective Optimization during Turning of AISI 8620 Alloy Steel using Desirability Function Analysis

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Abstracts

Quality and productivity plays a significant role in today's manufacturing industry. In multi objective optimization multiple performance characteristics need to be taken care of in order to avoid severe quality loss and also to ensure highest productivity. In order to tackle such a multi objective optimizaation problem, the present study applied Desirability functional analysis. The study aimed at evaluating optimum process parameters which could simultaneously satisfy the requirement of both quality as well as productivity. Experimentation is carried out using Taguchi's L9 orthogonal array on CNC lathe with AISI 8620 alloy steel and CVD coated tool combination. The process parameters such as spindle speed, feed and depth of cut are optimized by multi response consideration namely surface roughness and material removal rate. The optimal process parameters have been determined by the composite desirability value obtained from desirability function analysis and the contribution made by each parameters are determined by Analysis of variance (ANOVA). Confirmation test is also conducted to validate the experimentation. From the present study, it is concluded that surface roughness and material removal rate are significantly improved.

Keywords: Desirability function analysis(DFA), Orthogonal array, CNC lathe, AISI 8620 alloy steel, CVD coated tool, ANOVA

Introduction

The important goal in the modern industries is to manufacture the product with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process, the first is to determine the product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. The challenge of modern machining industry is mainly focused on achievement of high quality ,in terms of work piece dimensional accuracy, surface finish ,high production rate, less wear on the cutting tools ,economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Today metal cutting process places major portion of all manufacturing rocesses .Within these metal cutting processes the turning operation is the most fundamental metal removal operation in the manufacturing industry. Increase in productivity and the quality of the machined parts are the main challenges of metal based industry. There has been increased interest in monitoring all aspects of machining process. Surface finish and material removal rate are two important parameters are need to be considered in manufacturing industry to ensure aesthetic appeal to the product as well as improved productivity. Surface roughness has become the most significant technical requirement and is an index of product quality in order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product reasonably good surface finish is required. Now a day's manufacturing industries especially concerned to dimensional accuracy and surface finish. In order to obtain better surface finish and increased material removal rate, proper setting of cutting parameters is crucial before the process takes place factors such as spindle speed ,feed rate, depth of cut that control the cutting operation can be set up in advance . values of process parameters that will yield the desire In the present work, AISI 8620 alloy steel was selected as work material which finds applications in the manufacture of gears. pinions, lay shaft, cam shafts, mining haulage, cage suspensions, lifting gears, fasteners, chains and many more.For the purpose of experimentation, factorial design experiments are considered as per Taguchi DOE. By advocating Taguchi design, a clear understanding of the nature of variation and economical consequences of quality engineering in the world of manufacturing can be clearly got through. In the present study, Desirability function analysis was performed to combine the multiple performance characterstics in to one numerical score called composite desirability value to determine the optimal process parameter setting. Analysis of variance (ANOVA) is also performed to investigate the most

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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inflencing parameters on the surface roughness and material removal rate.

Literature review

W.H.Yang & Y.S Tang [1] envisages that the Taguchi method is a powerful tool to design optimization for quality and is used to find the optimal cutting parameters for turning operations. An orthogonal array , the signal to noise ratios and ANOVA are employed to investigate the cutting characteristics of S45C steel bars using Tungsten carbide cutting tools. Through this study, not only optimal cutting parameters for turning operations obtained, but also the main cutting parameters that affect the cutting performance in turning operations are found.

N.Tosum & l.Ozler[2] presented an investigation in optimization and effect of cutting parameters on multiple performance characteristics(the tool life and work piece surface roughness) obtained by hot turning operation. A plan of experiments based on Taguchi method was designed M20 sintered carbide as tool and high manganese steel as work material were used in the experiments. The results showed that the cutting speed, feed rate were dominant variables on multi cutting performance characteristics. An optimal parameter combination was obtained by using statistical Analysis
M.P. Jenarthanan & R. Jeyapaul[3] presents a new approach for optimizing machining parameters on milling glass-fibre reinforced plastic(GFRP) composites. Optimization of parameters was done by an analysis called desirability function analysis(DFA) which is a useful tool for optimizing multi response problems. A composite desirability value is obtained for multi- responses viz., surface roughness. Delamination factor and machining force using individual desirability values from DFA. Based on composite desirability value, the optimum levels of parameters have been identified and significant contribution of parameters is determined by analysis of variance.

T.Saravanan & R. Udaykumar[4] presents the machining of hybrid metal matrix using a mediumduty lathe. The optimum machining parameters have been identified by a composite desirability value obtained from desirability function analysis as the performance index and significant contribution of parameters can then be determined by analysis of variance.

Meenu Sahu and Komesh Sahu[5] presents an optimization method ofcutting parameters (cutting speed, depth of cut and feed) in dry turning of AISID2 steel to achieve minimum tool wear, low work piece surface temperature and maximum material removal rate. The experimental layout was designed based on Taguchi OA technique and ANOVA was performed to identify the effect of cutting parameters on the response variables. The results showed that depth of cut and cutting speed are the most important parameters influencing wear. Similarly low work piece surfacetemperature was influenced by cutting speed followed by depth of cut. The depth of cut and feed significantly influences high MRR. The optimal range of tool wear, work piece surface temperature and MRR were predicted. Finally the relationship between factors and performance measures were developed using multiple regression Analysis.

R.K.Suresh, P.Venkataramaiah and G.Krishnaiah[6] envisages an experimental investigation on turning of AISI 8620 alloy steel using PVD coated cemented carbide CNMG inset. Nine experimental runs based on Taguchi factorial design were performed to find out optimal cutting level condition. The main focus of present experimentation is to optimize the process parameters namely spindle speed, feed and depth of cut for desired response characteristics i.e. surface roughness, VMRR and interface temperature. To study the performance characteristics in this work orthogonal array(OA), analysis of means(ANOM) and analysis of variance(ANOVA) were employed.The experimental results showed that the spindle speed affects more on surface roughness, feed affects more on VMRR and feed affects more on interface temperature.Confirmation tests also been performed to predict and verifythe adequacy of models for determining optimal values of response characteristics.

Alaattin Kacal etal [7] dealt with experimental results of high speed hard turning of hardened ASIS S1 cold work tool steel with ceramic and CBN cutting tools. The results obtained from the experiments were evaluated graphically and by using ANOVA which is one of the statistical techniques.

Atul kulkarni, Girish joshi & V.G Sargade[8] used Taguchi method to optimize cutting parameters during dry turning of AISI 304 Austenitic stainless steel with PVD coated cemented carbide tool. The cutting speed, feed rate and coating thickness are considered as input parameters and flank wear and cutting force as response parameters. A multiple linear regression models are developed for responses.

From the literature survey, it is evident that no work has been reported on AISI 8620 alloy steel work with combination of CVD coated tool. Also little work has been reported on Desirability functin Analysis on

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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various machining operations. Hence the experimentation is done on above said combination of work piece and tool and optimization method-Desirability function analysis is put forth.

Materials & methods

Specification of work material

The work material used for the present study is AISI 8620 alloy steel. The chemical composition of the work material is shown in Table 1.

Table1

Element	carbon	silicon	Mn	Ni	Cr	Mo	S	P
% composition	0.18-0.23	0.3-0.6	0.6-0.1	0.4-0.7	0.4-0.6	0.15-0.25	0.04	0.035

Process parameters

Table 2

Cutting parameters	Level 1	Level 2	Level 3
Spindle speed,S(rpm)	450	580	740
Feed, F(mm/rev)	0.05	0.07	0.09
Depth of cut, D(mm)	0.10	0.20	0.25

Taguchi method

The objective of the robust design is to find the controllable process parameters setting for which Noise or variation as a minimal effect on the product or process functional characteristics. It is to be noted that the aim is not to find the parameter setting for the uncontrollable noise variables but the controllable design variables. To attain this objective, the control parameter also known as inner array variables, are systematically varied as stipulated by the inner orthogonal array. For the each experiment of inner array, a series of new experiments is conducted by varying the level settings of the uncontrollable noise variables. The level combinations of noise variables are done using the outer orthogonal array. The interference of noise on the performance characteristics can be found using the ratio where S is the standard derivation of the performance parameters of the each inner array experiment and N is the total number of experiment in the outer orthogonal array. This ratio indicates the functional variation due to noise. Using this result, it is possible to predict which control parameter settings will make the process in sensitive to noise. Taguchi method focus on robust design through use of Signal to noise ratio and Orthogonal array.

Analysis of variance(ANOVA)

Analysis of variance (ANOVA) is a statistical method of determining the existence of several While the aim of ANOVA is to detect the difference among several populations means the technique requires the analysis of different forms of variance associated with random samples under the study hence it is called ANOVA. The original idea of ANOVA was devolved by the English statistician sir Ronald A fisher during the first part of this century. most of the early work in this area deal with the agricultural experiments where crops were given different treatments, such as being grown using different kinds of fertilizes. The researchers wanted to determine whether all treatments under study were equally effective or whether some treatments were better than others

Desirability function analysis

Desirability function analysis is widely accepted method used in manufacturing industry. Desirability function analysis is used to convert multi response characteristics in to single response characteristic. Derringer and suich[9] popularized the concept of DFA as a simultaneous optimization technique which proved to be useful in solving multi response optimization problems. In view of this, complicated multi response characteristics can be converted in to single response characteristic which is termed as composite desirability. In the present study, multi responsed such as surface roughness and material removal rate are combined as composite desirability using desirability function analysis

The steps involved in the optimization process are detailed as follows

Step 1: The first step isto calculate desirability index(d_i) for each of the process parameters i.e surfaceroughness and material removal rate. The desirability index values are tabulated in table . It is calculated based on the desirability function shown in equations (1) and (2) respectively for the cases smaller is better and larger is better. In this study, surface roughness need tobe minimized and material removal rate need to be maximized.

Step 2: The second step is to evaluate the composite desirability based on equation (3)

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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Step 3: The third step is to determine optimality condition based on highest composite desirability index. Also the ranking of process parameters is estimated.

Step 4: The next step is to perform ANOVA by which contribution made by each parameter influencing the combined objective is estimated

Step 5: The last stage is to calculate the values from confirmity test based on optimum level of parameters is found out.

For smaller is better

$d_i = \frac{yi-ymax}{ymin-ymax}$ ………….. (1)

$d_i = \frac{yi-ymin}{ymax-ymin}$ ………….. (2)

where d_i is desirability index for a particular level

y_i is i^{th} normalized value

y_{min} is minimum of particular column values

y_{max} is maximum of particular column values

$dc = \sqrt[w]{d1^{w1} d2^{w2} d3^{w3} \ldots\ldots.. dn^{wn}}$……(3)

Experimentation & results

An CNC lathe (super jobber 500) was used for conducting the experiments. AISI 8620 alloy steel was used as the work material and CVD coated cemented carbide was used as the cutting tool. The average surface roughness on the work piece was measured using Mitutoyo SJ-201P surface roughness measuring instrument, material removal rate was measured by considering weights before and after turning operation and time taken. The experimentation of this work was based on Taguchi's design of experiments have been carried out. In this work, three cutting parameters namely, spindle speed, depth of cut and feed rate were considered for experimentation. Accordingly there are three input parameters and for each parameter three levels were assumed. For three factors, three level experiments, Taguchi had specified L9(3^2) orthogonal array experimentation was recorded and further analyzed. Table1 shows the parameters and their levels considered for experiment.The tests were carried for a work piece bar of 30mm diameter and 215 mm length on a CNC lathe(super jobber 500)

Table 3: Experimental data and results for 3parameters, corresponding Ra and MRR for CVD tool

SNo	Spindle speed(rpm)	Feed(mm/rev)	Doc(mm)	Surface roughness(µm)	Material removal rate(mm^3/min)
1	450	0.05	0.10	1.2130	51.870
2	450	0.07	0.20	1.1250	288.613
3	450	0.09	0.25	0.9678	476.167
4	580	0.05	0.20	1.3120	261.906
5	580	0.07	0.25	1.2250	541.901
6	580	0.09	0.10	1.0950	206.916
7	740	0.05	0.25	1.1967	407.997
8	740	0.07	0.10	1.2860	226.108
9	740	0.09	0.20	1.0882	544.693

Table 4: Evaluated results of composite desirability

Expt No	Normalized values(SR)	Normalized values(MRR)	Weighted desirability index(SR)	Weighted desirability index(MRR)	Composite desirability	Rank
1	0.2876	0.0000	0.5363	0.0000	0.0000	9
2	0.5433	0.4804	0.7371	0.6931	0.5109	3
3	1.0000	0.8609	1.0000	0.9278	0.9278	1
4	0.0000	0.4262	0.0000	0.6528	0.0000	8
5	0.2528	0.9943	0.5028	0.9971	0.5013	4
6	0.6304	0.3146	.7939	0.5609	0.4453	6
7	0.3349	0.7226	0.5739	0.8501	0.4919	5
8	0.0755	0.3536	0.2748	0.5946	0.1634	7
9	0.6502	1.0000	0.8063	1.0000	0.8063	2

Table 5: Response table for composite desirability

Process parameters	Average composite desirability				
	Level 1	Level2	Level3	Max-Min	Rank
Spindle speed	0.4796	0.3155	0.4870 *	0.1715	3
Feed	0.1639	0.3918	0.7264 *	0.5625	1
Depth of cul	0.2029	0.4391	0.6403 *	0.4374	2
Total mean value of the composite desirability = 0.4274 *Optimum levels					

Table 6 : Results of ANOVA

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F-ratio	Percent contribution
Spindle speed	2	0.056393	0.0281965	0.5922	6.667
Feed	2	0.409946	0.204973	4.3049	48.465
Depth of cut	2	0.284285	0.1421425	2.98537	33.609
Error	2	0.095226	0.047613		11.258
`	8				100.000

Confirmation test

The objective of the confirmation test is to validate the conclusions drawn during the analysis phase. Once the optimallevel of process parameters is selected, the next step is to verifythe improvement in response characteristics using optimum level of parameters. A confirmity test is conducted using the following equation:

$\gamma = \gamma_m + \sum_{i=1}^{n} \gamma i - \gamma m$, where γm is total mean of the required responses γj is the mean of the required resposes at optimum level n is the number of process parameters that significantly affects the multiple perfrmance characteristics Based on above equation, the estimated required responses(surface roughness and material removal rate) using ptimal processparameters as obtained from desirability function analysis can then be found out. Table shows the results of confirmation experiment using optimal process parameters. Surface roughness is improved from 1.213 to 0.98986 µm and material removal rate significantly improved from 51.870 to 406.155 mm^3/min. It is evident that multi response characteristics in CNC turing are greatly improved in this study.

Table 7: Comparison between initial machining parameters and confirmatory test results

	Initial machining parameters	Experimental result from confirmatory test
Setting level	S1-FI-D1	S3-F3-D3
Surface roughness (µm)	1.213	0.98986
Material removal rate (mm^3/min)	51.870	406.155

Conclusions

Turning experiments were conducted on CNC lathe based on Taguchi DOE for ASIS 8620 alloy steel using CVD coated cutting tool. The experimentation data were subjected to desirability function analysis for multi objective optimization. From this analysis, the following conclusions were drawn for surface roughness and material removal rate.

- Desirable functional analysis is a very useful and effective tool for multi objective optimization. By using DFA, multiple performance characteristics is converted in to single respose characteristic and is further used in the calculation of composite desirability index
- The implementation of DFA in the present study improves surface roughness from 1.213 to 0.98986 µm and material removal rate greatly improved from 51.870 to 406.155 mm^3/min
- Higher spindle speed, higher feed and higher depth of cut are optimum conditions of prosecc parameters for turning AISI 8620 alloy steel
- From ANOVA, feed signifies the most with a contribution of 48.46%, followed by depth of cut with 33.609%, spindle speed with 6.667% for lower surface roughness and higher material

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

removal rate simultaneously in turning of AISI 8620 alloy steel

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